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EUROPEAN PATENT APPLICATION

21 Application number: 80304485.8

22 Date of filing: 12.12.80

51 Int. Cl.³: A 61 C 5/08

A 61 C 5/10, A 61 C 13/08

30 Priority: 14.12.79 US 103647

43 Date of publication of application:
24.06.81 Bulletin 81/25

84 Designated Contracting States:
AT BE CH DE FR GB IT LI LU NL SE

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54 Dental appliance and method of manufacture.

57 A tooth crown or the like dental appliance made of a fired ceramic which undergoes substantially no shrinkage when fired, the appliance being made by forming a compact of the raw pre-fired ceramic with an undersurface shaped for a precise fit onto the prepared tooth on which the appliance is to be used, and thereafter firing the compact to dense, hard monolithic structure.

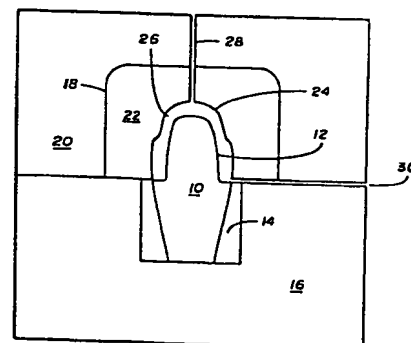


FIG. 2

DENTAL APPLIANCE AND METHOD OF
MANUFACTURE

TECHNICAL FIELD

5 This invention relates to a method for the fabrication of dental appliances such as crowns, bridges and the like, and to dental appliances made by such method.

10 For simplicity, the invention and its background will herein be principally with reference to tooth crowns and their manufacture, though it will be understood that the invention has application to other dental appliances such, for example, as dental bridges.

BACKGROUND ART

15 A dental crown is one of the most important restorations in dentistry in that it affords the restoration of deteriorated teeth to a state of health and function. One of the prime requisites for a successful dental crown is that it adapt as perfectly as possible to the prepared tooth structure (i.e. the tooth is
20 milled to a desired shape upon which the dental crown is placed). Anything less than substantially perfect fit, especially at the crown margin, can result in mechanical failure such as crown fracture or loosening or biologic failure such as decay, periodontal disease,
25 or occlusal problems. At the present state of the art the materials available for the fabrication of crowns include the noble metals such as gold base alloys, acrylics such as polymethyl methacrylate, dental porcelain, or a composite of a metal and a compatible
30 porcelain or acrylic.

At the present date the most widely employed method of fabricating dental crowns is to cast a metal

substrate which is subsequently covered with a dental porcelain veneer.

The metal substrate is obtained by an indirect process known as the "lost wax" technique. Specifically, 5 the substrate is first formed and shaped in wax. This involves making an impression of the prepared tooth, casting dental stone against the impression to form a master die, molding a body of wax against the master die and then shaping the upper portions of the wax body to 10 duplicate the external shape of the tooth crown desired. The wax form must then be accurately converted to the metal. To accomplish this the wax form is invested into a refractory material, thus forming a mold. The wax is then eliminated by melting or burning, thus creating 15 a cavity into which the metal, heated to a molten state, is cast. Hence, the wall of the cavity intended to be an exact replica of the prepared tooth can suffer inaccuracies because of the three-step technique needed to prepare it--preparation of the master die, preparation 20 of the wax form from the master die, and preparation of the mold from the wax form. This renders the process technique-sensitive. The process is even further technique-sensitive in that each metal alloy possesses a specific casting shrinkage for which there must be 25 accurate compensation. This compensation is critically dependent upon the proper selection and skillful manipulation of all materials employed. The technique is sensitive in that failure can occur at any of the numerous steps involved, such as distortion of the wax 30 form, improper investing procedure, inadequate expansion of the mold, improper burn-out procedure, or improper melting and casting of the metal. A principal drawback of this technique is that many hours are consumed before a failure in the casting stage can be detected. 35 The success or failure of the composite ceramic-metal

crown is also greatly dependent on the proper finishing and handling of the surface of the metal to which the ceramic is applied. Proper finishing which is difficult and time consuming, is essential to the successful bonding of the ceramic to the metal substrate. Still further, the inherent physical differences between the porcelain veneer and the metal substrate, such as differences in thermal expansion, give rise to numerous potential avenues for failure.

10 An alternative technique, which eliminates the need for a metal casting, is to form the crown of a dental porcelain with a thin underlayer of platinum foil. The thin platinum foil is carefully shaped to a replica of the prepared tooth and the dental porcelain is then overlaid onto the foil which supports the porcelain during the subsequent firing cycles necessary. This procedure is extremely technique-sensitive, requiring skillful and meticulous processing. Proper and accurate shaping of the platinum foil over the replica is extremely difficult and frequently leads to poorly fitted crowns. Additional problems of fit arise due to the shrinkage of the dental porcelain which often distorts the thin platinum matrix during firing. It is therefore more difficult to obtain the desired fit with this crown as compared to the cast metal-porcelain composite.

DISCLOSURE OF THE INVENTION

30 The present invention provides a dental appliance which has excellent strength, durability, density, appearance and fit but yet which can be made at relatively low cost both by reason of the material used and, even more significantly, by reason of simplified processing. In accordance with the invention, the tooth crown or other dental appliance has a

tooth-engaging substrate formed of a shrink-free ceramic. Where, as is generally the case, it is desired that the appliance have greater translucence and closer color match to that of the natural tooth, the substrate is coated on its outer surfaces with a porcelain or glaze veneer having the whiteness and degree of translucency desired.

A preferred shrink-free ceramic for the practice of the invention will be described in detail hereinafter; however, suffice it to say at this point that by the term "shrink-free ceramic" is meant a ceramic made from a ceramic powder formulation which, when compacted and then fired to maturity, converts to a dense, hard, monolithic body which has substantially the same volume and shape as were the volume and shape of the ceramic powder compact prior to firing. Because the ceramic does not undergo shrinkage when fired to maturity, i.e. to high strength and hardness, the powder compact can, prior to firing, be formed to the identical size and shape desired for the crown or other appliance with complete assurance of the required perfect fit to the prepared tooth to which it is to be secured. And because the ceramic powder can be readily molded at relatively low temperature into a compact of any desired shape and with the resulting compact itself being relatively soft such that portions thereof can be easily removed for any further shaping as might be required, the invention provides much simplified processing for dental crowns or other appliances having the required perfect fit along with high strength and all other desired characteristics.

Fundamentally, the method of the present invention involves only three essential steps, namely: (1) preparation of a die which is an exact replica of the prepared tooth to which the crown or other dental

appliance is to be fitted; (2) molding or otherwise forming a compact of the raw particulate shrink-free ceramic against the die and simultaneously, or thereafter, shaping the remaining surface portions of the compact to the shape and size desired for the appliance; and (3) firing the so-shaped compact to its maturing temperature. As a last step, generally necessary for purposes of matching the appearance of the natural tooth, the fired shrink-free ceramic substrate, so manufactured, is coated with a suitable porcelain veneer or glaze thereby completing preparation of the appliance which is thereafter secured to the prepared tooth.

As will be discussed in greater detail hereinafter, the first step--that of preparing the die--can be accomplished by the technique currently and for many years used for preparation of the master dies for making dental crowns and other appliances by the prior art methods such as those described above. Then, a mold is prepared with the die as a wall portion thereof. To this end wax (which can be a wax such as paraffin or some other thermoplastic such as an acrylic or other synthetic thermoplastic polymer) can be molded against the die, after which the remaining surfaces of the resultant wax body can be shaped to duplicate the external crown shape desired. Dental stone or the like is then cast against the wax body thereby to form a mold in which the die itself serves as the mold wall intended to be an exact replica of the prepared tooth. Mold preparation is completed by melting or burning out the wax or other thermoplastic material. Such mold is then used for shaping the shrink-free ceramic to the crown shape desired. Hence, the surface portion of the crown which fits against the prepared tooth is formed by shaping it against the die itself rather than against a mold wall prepared from a wax body shaped by molding the wax against the die. This

process simplification greatly increases the closeness and accuracy of fit of the crown to the prepared tooth and it is enabled by the fact that the shrink-free ceramic can be shaped at low temperature, as compared
5 with the temperatures required for casting metal.

In the preferred method as just described, the entire final shape of the shrink-free ceramic compact is accomplished simultaneously with the shaping of that portion of the compact which, after firing, is
10 to fit against the prepared tooth. However, it is within the purview of the invention to form the non-tooth engaging portions of the compact to the final desired shape subsequent to forming the compact against the die. That is, the wax body formed against the die can, if desired,
15 be shaped on its external surfaces only roughly to the external shape desired of the compact, leaving it for further and final shaping of such surfaces of the compact after it has been molded. As has already been mentioned, such final shaping of the powder compact is relatively
20 simple, since the compact is quite soft prior to firing.

The above and other features and advantages of the invention will appear more clearly from detailed description of preferred embodiments which follows.

BRIEF DESCRIPTION OF THE DRAWINGS

25 FIGURE 1 is a flowchart showing steps involved in the practice of a preferred embodiment of the invention;

FIGURE 2 is a schematic view of molding apparatus for practice of the preferred embodiment; and

30 FIGURE 3 is a cross sectional view of a dental appliance embodying and fabricated by the method of the present invention.

BEST MODE FOR CARRYING OUT THE INVENTION

As has already been made clear, a key feature of the present invention is the use of shrink-free ceramic as the material for the dental appliance substrate. Various shrink-free ceramics have been proposed for use as industrial ceramics but before further discussing them, it is appropriate to mention briefly some of the characteristics of more conventional ceramics and their manufacture.

Conventional ceramic bodies, typically alumina ceramics, are manufactured by forming a raw batch of the desired ceramic ingredients in particulate form, (e.g. aluminum oxide) plus a binder, molding or otherwise forming the raw batch into a compacted body, and then firing the compacted body to sinter or vitrify the ceramic.

During the firing operation there is considerable shrinkage--generally from about 10% to 20%--which means that the compact must be made larger than the desired fired body. Also, because shrinkage is never exactly uniform throughout the body, there is always a certain amount of warpage or distortion--though with good quality control it is generally possible to maintain warpage or distortion within the bounds of normal tolerances for electrical insulators, mechanical components and the like industrial ceramic bodies.

Shrinkage occurs for one of a combination of two reasons. First, no matter that even high pressure is used to mold or otherwise form the compact, the density of the compact is not as high as theoretically possible--there is always some porosity--to the end that there is some shrinkage when the compact fires to a high density non-porous monolith. The use of an organic binder in the compact, which is generally desirable to add green strength, may contribute to the porosity of the compact since it is vaporized or burned out during the subsequent firing operation to mature the

ceramic to dense monolithic structure. Secondly where the ceramic ingredients undergo chemical or crystalline transformation during the firing, if the ceramic formed is of greater density and lesser volume than the raw ceramic ingredients, then this also contributes to the shrinkage.

Generally, reason (1) cannot be entirely eliminated even for the manufacture of shrink-free ceramic bodies. However, in the case of most shrink-free ceramic bodies, the formulation of raw particulate ceramic ingredients is one wherein one or more of the ingredients undergo either chemical or crystalline transformation during the firing and with the resultant ceramic formed by way of the chemical or crystalline transformation occupying a greater volume than that of the raw ingredients, to the end that this increase in volume exactly compensates for the decrease in volume caused by reason (1). Hence, for example, it is known that kyanite converts to mullite and silica upon firing, the combined volumes of the mullite and silica being greater than the volume of the kyanite. Accordingly, it is known to formulate a ceramic batch of kyanite, generally along with other ceramic ingredients, the amount of kyanite being such as to produce, during firing, a volume increase sufficient to compensate for the shrinkage which would otherwise occur by reason of the inclusion of binder and the relatively high porosity of the compact prior to firing. Various and diverse examples of shrink-free ceramics are discussed in the article entitled "Porcelains Having Low-Firing Shrinkage", Volume 43, No. 5 (1964) Ceramic Bulletin of the American Ceramic Society. United States Patent 3,549,393 Elarde also discloses such ceramics.

In addition to being shrink-free, the ceramic used in the practice of the invention should have high flexural strength (preferably above 15,000 psi), high compressive strength (preferably above 50,000 psi),
5 low porosity and commensurately high density (preferably above 80% of the theoretically highest density possible for the ceramic used), and a low coefficient of thermal expansion (preferably below $8.0 \times 10^{-6}/^{\circ}\text{C}$).

The preferred shrink-free ceramic, and
10 processing thereof, for the practice of the present invention is that set forth in United States Patent Application P-400 in the names of Lynn B. Starling, James E. Stephan, and Robert D. Stroud, filed concurrently herewith. Such shrink-free ceramic body
15 utilizes the fact that when aluminum oxide and magnesium oxide combine, during firing, to form magnesium alumina spinel ($\text{MgO Al}_2\text{O}_3$) there is a volume increase. Also, in this preferred shrink-free ceramic the binder used is a silicone resin containing
20 a high percentage (upwards of about 50% by weight) SiO groups to the end that upon binder burnout during firing, a major portion thereof remains in the resulting ceramic body as silica or silicate.

The following is the most preferred batch
25 formulation for such shrink-free ceramic:

Al_2O_3 (particle size, .4 to 10 microns - average 2.5 microns)	100 grams
Al_2O_3 (-325 mesh, Tyler)	40 grams
$\text{BaO} \cdot \text{SiO}_2 \cdot \text{Al}_2\text{O}_3$ glass 30 (53% BaO , 42% SiO_2 , 5% Al_2O_3)	30 grams
MgO (-200 mesh, Tyler)	20 grams
Edgar plastic kaolin	9 grams
Calcium stearate	2 grams
Acrawax C (steryl amide wax, 35 melting temperature 290°F)	2 grams

silicone resin

28 grams

The varied particle size of the ceramic batch is to provide high compaction density. The calcium stearate and Accrawax function as lubricants during the compaction operation. When the above body is fired to a temperature of about 1300°C, the magnesia and some of the alumina combine to form the spinel, and other of the ingredients, including silica from the silicone resin, form a glassy phase, the resultant matured body being possessed of a high density (approximately 2.7g/cc.), excellent physical strength (flexural strength upwards of 15,000 psi; compression strength upwards of 50,000 psi) and a low coefficient of thermal expansion (below $6.0 \times 10^{-6}/^{\circ}\text{C}$). During the firing there is no significant shrinkage, and in this regard it is desirable to fire the ceramic on a gradual schedule, for example, by first gradually heating to about 500°C and holding the body there for about 16 hours, and thereafter gradually raising the temperature, over a period of about 9 hours, to 1300°-1320°C, but with substantially no hold being required at this highest firing temperature. By way of the gradual heating, escape of SiO groups from the silicone resin is inhibited to the end that substantially all of the SiO groups of the silicone resin remain in the fired body as silicate.

As discussed in the aforementioned patent application filed concurrently herewith, variations from the above formulation can be used, the key ingredients in the preferred formulation being the alumina and magnesia, the glassy or glass-forming ingredients to provide a glassy phase; and silicone

resin having a high percent of SiO groups--upwards of 50%--to function as the binder.

It will be also understood that whereas the afore-described ceramic has, to date, been found to be best and hence is most preferred, other shrink-free formulations can be used for the practice of the invention.

Reference is now made to the flowchart shown in FIGURE 1.

The first step involves preparation of the die to the precise shape of the prepared tooth. This can be accomplished in the manner currently used and well-known to those skilled in dental art. Briefly, the dentist prepares the tooth to be crowned by removing enough of the tooth structure to allow proper thickness of the final crown, after which the dentist secures a negative of the prepared tooth with a suitable impression material. The die is then made by molding or casting dental stone or the like into the negative. Thereafter this die is related to a model of the opposing arch (upper to lower teeth) on an articulator which simulates jaw movements. Where the die at this stage is of multiple teeth, the dies for the individual teeth to be crowned are then separated by fine saw blades to allow easy manipulation of the dies and then trimmed, i.e. ditched, such that the margins (the exact point where the crown is to end) are visible and accessible, all as well known in the dental art.

Next the die, duplicative to the tooth to be crowned, is secured to form a portion of a mold for the molding of the shrink-free ceramic raw batch. Reference is made to FIGURE 2 which depicts such a mold. In FIGURE 2, 10 is the die the outer surface 12 of which is duplicative of the prepared tooth to be crowned and the lower portion of which is simply a base set into an anchoring material 14, such as

gypsum, within a recess in a lower mold block 16. Within a recess 18 in an upper mold block 20 is a female mold 22 the inner surface 24 of which defines, in combination with the die, the mold cavity 26 for molding the shrink-free ceramic formulation. An opening 28 is provided for admission of the shrink-free ceramic formulation into the mold and a second opening 30 is provided as a vent for the escape of air during the admission. Prior to use of the mold for molding the shrink-free ceramic it is best to apply to the surface of the mold cavity a thin film of a suitable mold release agent, such as stearic acid or colloidal graphite.

Cardinal to the invention is that a shrink-free ceramic formulation be shaped against the die under sufficient pressure to assure complete conformity of the shrink-free ceramic formulation to the die. It is desirable, though not essential to the practice of the invention in its broadest scope, to accomplish this by a molding operation wherein the mold shape is such that the outer surfaces of the substrate which is molded are of the final shape desired. This involves preparation of the female mold to provide such shape and this can be accomplished by the use of a "lost wax" technique. That is, a wax, such as paraffin, or a thermoplastic polymer such as an acrylic or the like heat softenable material is applied over the surface of the die and built up and sculptured to the external shape of the desired substrate after which a material, such as gypsum, is cast against the wax or the like material and allowed to set to hardness. The assembly is then heated to burn out or melt out the wax, thermoplastic polymer or the like.

Particularly where the mold is so prepared so as to mold the shrink-free ceramic formulation to the final shape desired for the substrate, it is

preferred that the molding operation be one of transfer molding, as set forth in the aforementioned Patent Application P-400 filed concurrently herewith. Briefly, the method involves the preparation of a pre-form of the compacted shrink-free ceramic formulation, this pre-form being thereafter heated sufficiently to where it is flowable and the material thereof transferred by pressure into the mold. Just as is true of compression molding and injection molding, either of which can be used for the practice of the invention, transfer molding is broadly well-known in the plastics molding art. In this regard, it should be mentioned that where the binder used in the shrink-free ceramic formulation is a silicone resin, the overall formulation can be considered, for purposes of molding, as a highly filled organic polymer, and since silicone resin softens prior to curing, it can be either compression molded at a temperature to cause it to cure or it can be injection molded at a lower temperature at which it remains a thermoplastic. Where the preferred shrink-free ceramic formulation specified above is used and is formed into a compact by molding, it is quite satisfactory to use a molding temperature of about 150°C.

The molding can also be accomplished by the so-called isostatic molding technique which is well known in the industrial ceramics manufacturing art and which is really more in the nature of a cold pressing operation. Briefly, isostatic molding involves the use of an elastomeric mold to which hydraulic or the like external pressure is applied thereby to compress and compact the ceramic raw batch contained therein into a self-sustaining compact.

As has been alluded to earlier herein, it is

not necessary to the practice of the invention, in its broadest scope, to mold the shrink-free ceramic formulation to the precise external shape desired for the substrate but rather it is only
5 necessary to mold the tooth engaging portion thereof (i.e. the portion molded against the die) to the final desired shape. Hence, the mold surface portion depicted at 24 in FIGURE 2 need not be shaped to the precise external shape desired for the substrate. Instead,
10 the substrate can be molded to another external shape, e.g. to only approximately the final external shape desired, and then after the molding operation, the final desired external shape can be imparted to the molded substrate as by removing portions thereof to
15 impart the final desired shape. This is easily accomplished because the shrink-free ceramic in its unfired state is quite soft, with a chalk-like consistency, and hence can be readily sculpted. Of course in all cases the sprue and any flash are
20 best removed prior to firing.

After the molding operation the molded substrate is fired to mature the ceramic as previously described. Since there is no shrinkage during the firing operation, the fired crown is of precisely
25 the same shape and volume as prior to firing.

As a last step, generally necessary to simulate the appearance of a natural tooth, a veneer is applied to the fired substrate. This involves coating the external surfaces of the substrate with a porcelain
30 frit or glaze and then heating to cure the veneer. It will be understood that the precise composition of the veneer will depend on the whiteness and translucency desired for the crown, or other appliance, and the degree of whiteness of the substrate itself. Hence,
35 in some instances the veneer can be a translucent glaze and in other substances, more common, it will be a white dental porcelain of the general type currently

used for veneering cast metal substrates. However, in all cases it is preferred that the veneer selected have a coefficient of thermal expansion which matches or is close to that of the fired shrink-free ceramic substrate.

FIGURE 3 is illustrative of a crown made in accordance with the invention, the crown consisting of the shrink-free ceramic substrate 32 coated with a thin veneer 34 and secured by a suitable dental cement to the prepared tooth 36.

It will be understood that whereas the invention has been described in its details with reference to preferred embodiments thereof, various changes and modifications may be made all within the full and intended scope of the claims which follow.

What is claimed is:

1. A method for making a dental appliance adapted to be secured to a natural tooth after the
5 natural tooth has been prepared, by removing portions thereof, for reception of the appliance, said method comprising the steps of forming a compact of a raw particulate shrink-free ceramic to provide said compact with a recess as an undersurface and with an upper
10 surface which at least approximates the shape of the natural tooth prior to preparation of the tooth for said appliance, said recess having a shape substantially identical to that of the tooth after its preparation for the appliance; and thereafter firing said compact to a
15 hard monolithic body substantially identical in shape and size to said compact prior to firing.

2. A method as set forth in Claim 1 wherein said fired body is coated with a veneer which simulates
20 the appearance of the natural tooth and is then again fired to cure the veneer.

3. A method for making a dental appliance comprising the steps of preparing a die having a shape
25 substantially identical to that of a prepared tooth to which the appliance is to be secured, forming against said die a compact of a raw particulate shrink-free ceramic and thereafter firing said compact to dense monolithic structure.

30

4. A method as set forth in Claim 3 wherein said compact is formed against said die in a mold cavity having said die as a wall portion thereof.

35 5. A method for making a dental appliance to be secured to a prepared tooth comprising the steps of:

- a. taking an impression of the prepared tooth in a body of pliant material thereby to form an impression in said body of material identical in shape to that of the prepared tooth;
- 5 b. molding another body of material into and against said impression thereby to form a die which is a replica of the prepared tooth;
- c. molding a body of thermoplastic material against said die and shaping the exposed surface portions of said body of thermoplastic material to the
10 shape desired for the external surfaces of the appliance;
- d. shaping a body of material against the shaped body of thermoplastic material while the shaped body of thermoplastic material remains on said die,
15 thereby to form a female mold with an internal shape identical to the external shape of the body of thermoplastic material;
- e. applying heat to said body of thermoplastic material to cause its removal from said die and
20 female mold thereby to provide a mold cavity between said die and female mold;
- f. forming a body of particulate raw shrink-free ceramic in said mold cavity thereby to form a compact of said raw shrink-free ceramic having as an
25 undersurface a recess of a shape identical to that of the die and having an upper surface of a shape identical to that of the female mold; and
- g. thereafter firing said compact to a hard monolithic ceramic body of a shape and size substantially identical to the shape and size of said compact
30 prior to said firing.
6. A dental appliance adapted to be secured to a prepared tooth, said appliance comprising a hard
35 monolithic body of shrink-free ceramic having a surface

portion in the form of a recess shaped for a substantially perfect fit onto the prepared tooth.

7. A dental appliance as set forth in Claim 6
5 wherein surface portions of said body other than those of the recess are coated with a veneer which simulates natural tooth appearance and which has a coefficient of thermal expansion which at least approximates that of said body.

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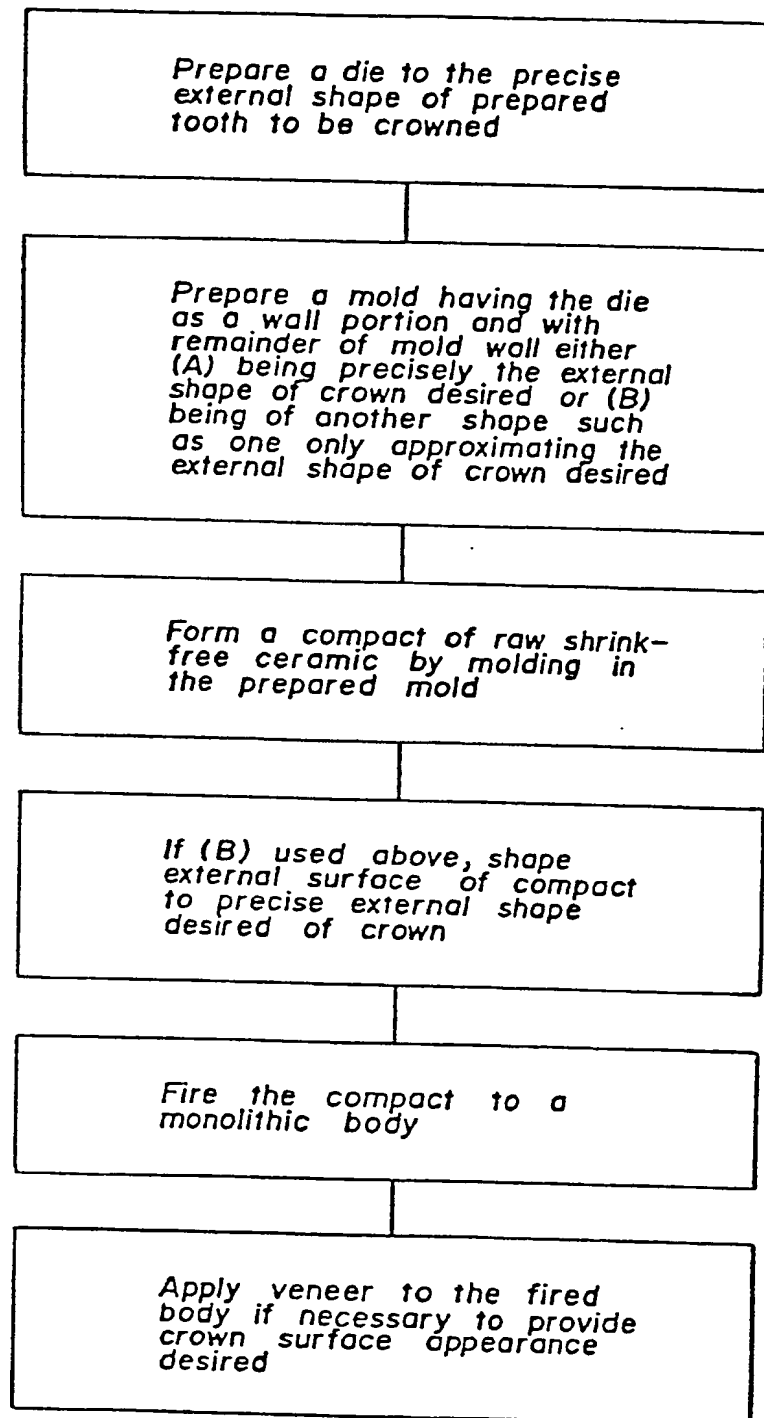


FIG. 1

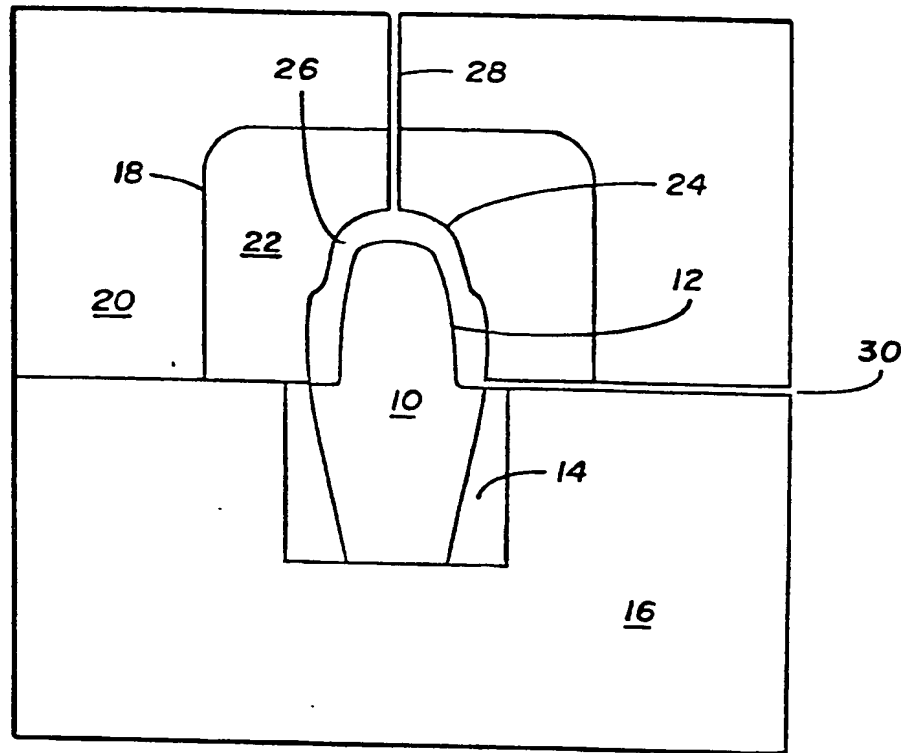


FIG. 2

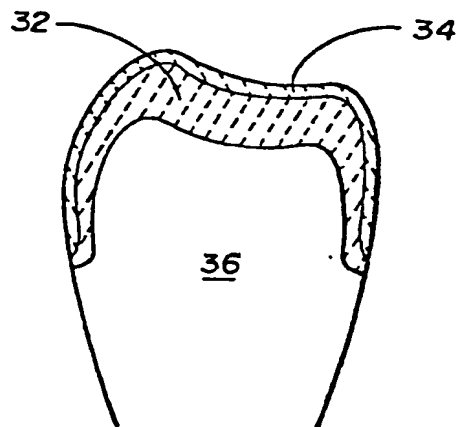


FIG. 3

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European Patent
Office

EUROPEAN SEARCH REPORT

Application number

EP 80 30 4485.8

DOCUMENTS CONSIDERED TO BE RELEVANT			CLASSIFICATION OF THE APPLICATION (Int. Cl.)
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	
	<u>US - A - 3 464 837</u> (McLEAN et al.) * column 2, lines 7 to 14; fig. 1 * --	1,2	A 61 C 5/08 A 61 C 5/10 A 61 C 13/08
	<u>DE - C - 674 674</u> (ROSENTHAL-ISOLATOREN) * page 1, lines 1 to 29 * --	1,6	
	<u>DE - A - 2 052 635</u> (CERAMCO) * claim 1; page 7, line 24 to page 8, line 6 * --	1,6	
			TECHNICAL FIELDS SEARCHED (Int. Cl.)
D	<u>US - A - 3 549 393</u> (ELARDE) --		A 61 C 5/00 A 61 C 13/00
A	<u>AT - B - 124 442</u> (HÜSTEN) --		
A	<u>DE - C - 603 164</u> (BRILL) --		
A	<u>DE - C - 292 406</u> (CASPARI) --		
A	<u>GB - A - 1 502 813</u> (ROGERS) --		
A	<u>US - A - 2 317 103</u> (MEIER) --		CATEGORY OF CITED DOCUMENTS
A	<u>US - A - 2 249 890</u> (DRÖGE) --		X: particularly relevant A: technological background O: non-written disclosure P: intermediate document T: theory or principle underlying the invention E: conflicting application D: document cited in the application L: citation for other reasons
A	<u>US - A - 2 000 285</u> (HOFFMANN) -----		
<input checked="" type="checkbox"/> The present search report has been drawn up for all claims			&: member of the same patent family, corresponding document
Place of search		Date of completion of the search	Examiner
Berlin		09-03-1981	SIMON